Investigation of wave field stability for sound propagation in the structured ocean: A dynamical systems approach to wave propagation in random media

Michael A. Wolfson
Applied Research Laboratory
College of Ocean and Fishery Sciences
University of Washington
Seattle, WA 98105-6698
Phone: (206) 543-1320   Fax: (206) 543-6785   email: wolfson@apl.washington.edu

LONG-TERM GOALS

The proposed effort is to investigate the limits of using semiclassical methods to capture the essential physics of acoustic pulse propagation in the ocean waveguide.

OBJECTIVES

Our specific objectives are to test when geometric acoustics is an appropriate tool for predicting the statistics of acoustic wave fields transmitted over thousands of kilometers in the world's oceans. We focus our attention on ocean environments where volume inhomogeneities due to mesoscale energetics and internal waves are the assumed sole source of range dependence in the sound speed. For the most part we have constrained our studies to two-dimensional wave propagation along the vertical plane.

APPROACH

Much of our approach is based on formulating a hypothesis based on results from numerical simulations. A full wave acoustic propagation model based on the parabolic approximation using a wide angle propagator [1] is used as a *ground truth* guide for testing our hypothesis. The geometric acoustics (ray tracing) model was tested to ensure exact agreement with the full wave simulations for range-independent environments. Our background sound speed fields are derived from either CTD casts from the North Pacific Ocean or the Levitus ocean climatology database [2] of temperature and salinity via the equation of state of Del Grosso [3]. Our most significant results use sound speed fluctuations due to GM internal waves [ref]. The internal wave model which generates the sound speed flucuations is similar to the one used by Wolfson and Spiesberger [4] but the range scale of 1000 km was used for the spectral composition, avoiding the statistics preserving problem associated with "patching" smaller range segments together.

Although observables such as travel time were compared, emphasis was placed on the more robust observable of depth scattering. This observable is nearly insensitive to the acoustic source bandwidth as well as being numerically efficient with respect to the geometric acoustic model since there is no constraint requiring the determination of eigenrays. The measure of depth scattering used is based upon choosing a integrating over a *time windowed* portion of the received acoustic field intensity ψ about lower turning point caustic nearest to a predefined sound speed slowness:

Report Documentation Page

1. REPORT DATE **30 SEP 2003**	2. REPORT TYPE	3. DATES COVERED **00-00-2003 to 00-00-2003**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Investigation of wave field stability for sound propagation in the structured ocean: A dynamical systems approach to wave propagation in random media	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Applied Research Laboratory,,College of Ocean and Fishery Sciences,,University of Washington,,Seattle,,WA,98105**	8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**Same as Report (SAR)**	**4**	

$$I(z) = \frac{1}{\Delta T} \int_{-\Delta T}^{\Delta T} | \psi(z,t;r) |^2 \,,$$

where the calculation is performed over the depth z at and below the prescribed lower turning point at the range r. The time window ΔT is adjusted to isolate the scattering about a single pair of lower turning point caustics. The pair of caustics corresponds to acoustic energy which initially predominantly propagates both upward and downward, and has encountered the same number of upper turning points.

One of the key individuals participating in this effort is F. Henyey at the APL, University of Washington. Individuals collaborating on related efforts include M. Brown and F. Beron-Vera at RSMAS, University of Miami, J. Colosi at WHOI, S. Tomsovic at Washington State University, and G. Zaslavsky and A. Virovlyansky at New York University.

WORK COMPLETED

Results relating to the above work, but with an emphasis on the theoretical formulation of intensity and travel time fluctuations based on geometric acoustics were published recently in the Journal of the Acoustical Society of America. Several manuscripts are in preparation relating to work completed during the last fiscal year:
1.   Numerical investigation of the semiclassical breakdown in the presence of ray chaos (co-author M. Brown),
2.   Interaction strength as a criterion for the breakdown of the ray approximation for waves in random media (co-author F. Henyey),
3.   Limit of validity of ray tracing for long-range ocean acoustic propagation (co-author F. Henyey).

RESULTS

We have discovered that, contrary to what is currently believed, geometric ray theory, including known semiclassical wave field representations, cannot be used to model long-range ocean acoustic propagation at frequencies of order 100 Hz. The range dependence of the breakdown is seen to be inversely related to the scattering strength of the ocean medium, $k_0 \mu L_P$, where k_0 is the reference acoustic wave number, and μ and L_P represent the rms strength and correlation length scale of the refractive index inhomogeneities. This fundamental result has been numerically obtained by observing the disagreement in modal content from full wave and ray based simulations for ranges as short as 50 km, and we have interpreted the result in terms of an interaction strength criterion for the broader field of waves propagation in random media (WPRM). In terms of rays, one can no longer make the association that the vertical wave number corresponds to the gradient of the ray phase.

Our results are significant since low frequency sources are desirable for long-range propagation due to their minimal attenuation characteristics, and ray models are desirable for relevant applications such as acoustic tomography since they are numerically less costly than their full wave counterparts.

IMPACT/APPLICATIONS

We now understand the root of the breakdown in ray tracing, and this assists us to not only map out the range and frequency space where ray tracing is justified, it guides us to attempt to derive a full wave transport theory which can be appealed to outside its limits of applicability.

RELATED PROJECTS

The experiments associated with the North Pacific Acoustic Laboratory (NPAL) are closely related to this work since these experiments involve propagation distances and sources relevant to our results (htpp://npal.ucsd.edu)

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